

GRAVITATIONAL-WAVE EM COUNTERPART KOREAN OBSERVATORY (GECKO)



Originally, KU collaboration

Myungshin Im (SNU)

Chung-Uk Lee (KASI), Seung-Lee Kim (KASI), Hyung Mok Lee (KASI), Sung-Chul Yoon (SNU), Joonho Kim (SNU), Gregory S. H. Paek (SNU), Sophia Kim (SNU), Sungyong Hwang (SNU), Gu Lim (SNU), Changsu Choi (SNU), Seong-Kook Lee (SNU), Yongmin Yoon (SNU), Yongjung Kim (SNU), Dohyeong Kim (KIAA), Wonseok Kang (NYSC), Taewoo Kim (NYSC), Hyun-Il Sung (KASI), Z. Lucas Uhm (KASI), Soojong Pak (KHU), Chunglee Kim (Ewha Womans Univ.), Sanghoon Oh (NIMS) & GECKO team/friends



TALKS TODAY

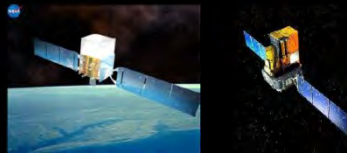
- GECKO overview
- KMTNet follow-up (Joonho Kim)
- G190425z event + other follow-up issues (Gregory Paek)

GW170817: NS-NS MERGER MULTI-MESSENGER ASTRONOMY

- 2017-08-17 GW event marked the start of MMA using GW and EMW signals
- 3700 (39@Korea, 45 countries, 900+ institutions, 80 facilities), 59 page ApJL paper



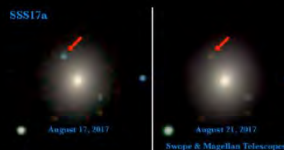
2017-08-17 12:41:04 UTC
라이고 및 비르고 중력파 신호 포착



+2초 후
페르미 및 INTEGRAL 감마선 신호 포착



KMTNet(서울대/한국천문연구원)



+약 11시간 후
칠레 천문대 망원경들이
가시광선 신호 포착



+약 21시간 후
국내연구진 호주 이상각망원경으로
추적관측시작. 이후 약 4주간 추적관측
(KMTNet, BOOTES-5망원경 등)



+약 9일 후
찬드라 우주망원경
X-선 신호 포착

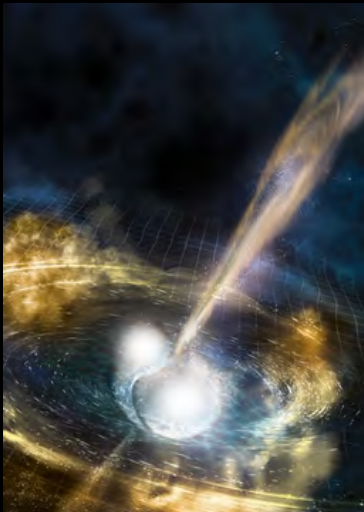


+약 16일 후
지상 전파망원경
전파 신호 포착

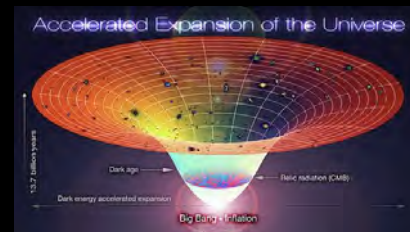
그림출처: LIGO, NASA, 1M2H/UC Santa Cruz and Carnegie Observatories/Ryan Foley,
서울대/한국천문연구원/임명신, NSF/Sonoma 주립대/A. Simonnet, NRAO

ANSWERS TO KEY QUESTIONS

- Binary neutron star merger → short GRB-like event? **YES, but off-axis or cocoon?**
- EM counterpart = Kilonova? **YES, but is this typical?**
 - blue or red? **Both**
 - Brightness? **17 mag in the beginning**
- Environment of NS merger? **Massive elliptical galaxy, near center, but it looks strange**



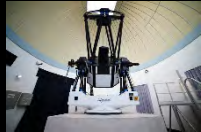
Gold!
(200 M_E)



H_0 from GW
(but need more)



GW EM COUNTERPART KOREAN OBSERVATORY (GECKO)



Korea: SNU 0.6, **1.0m**
SOAO 0.6m DOAO 1.0m



Hawaii: UKIRT, **Gemini-N**

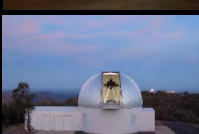
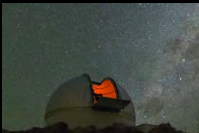
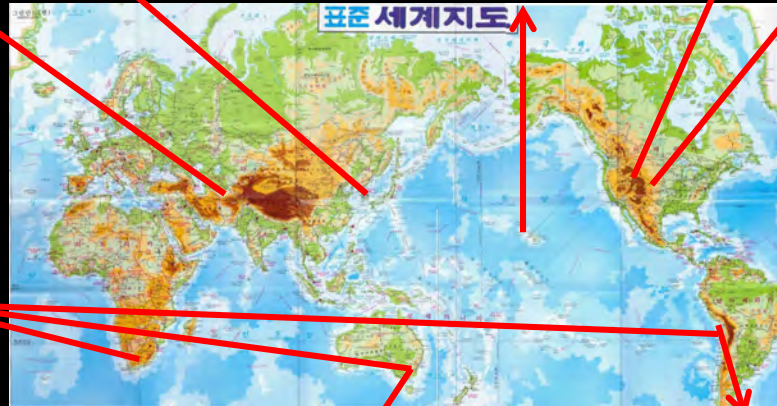
US: LOAO 1-m



Maidanak:
1.5m Telescope



US: McDonald
2.1-m, 0.8m,
0.25m



KMTNet 1.6m



Australia: LSGT 0.43m (SSO), KMTNet

Chile: **Gemini-S**, KMTNet



Yellow: Spectroscopy

Light yellow: medium-band



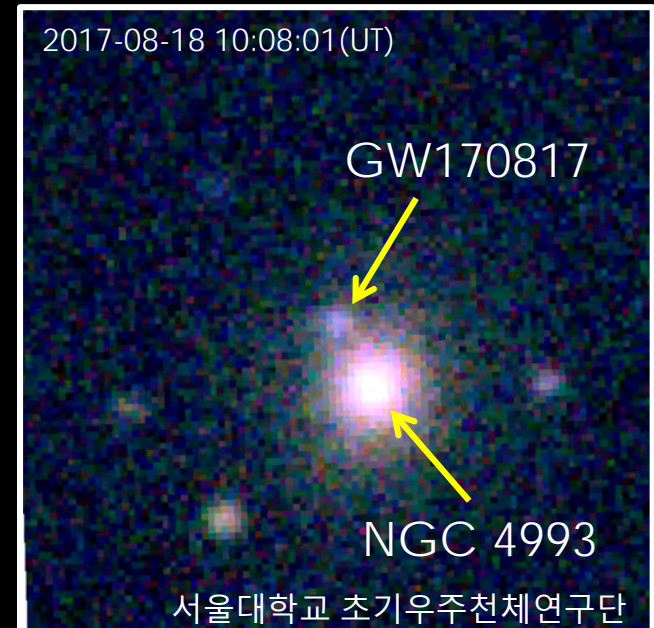
FIRST KOREAN OBSERVATION

- At 2017-8-18, about 21 hours after the GW detection, the GW EM counterpart was detected by LSGT (0.43m telescope!)



서울대학교 초기우주천체연구단

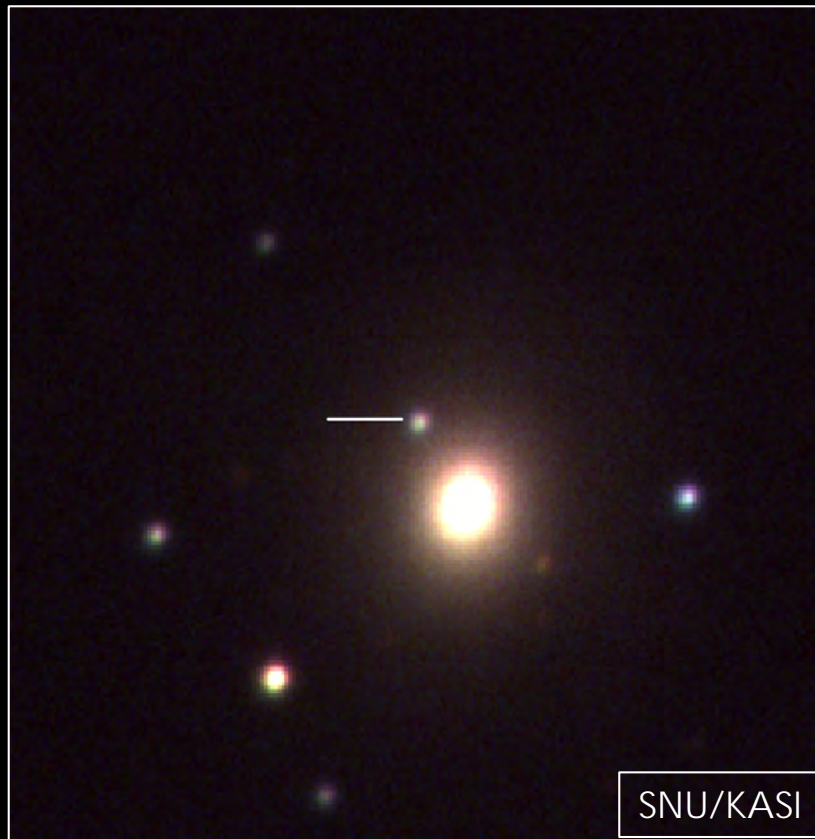
Lee Sang Gak Telescope
(Siding Spring Observatory)



Optical counterpart detection
by LSGT



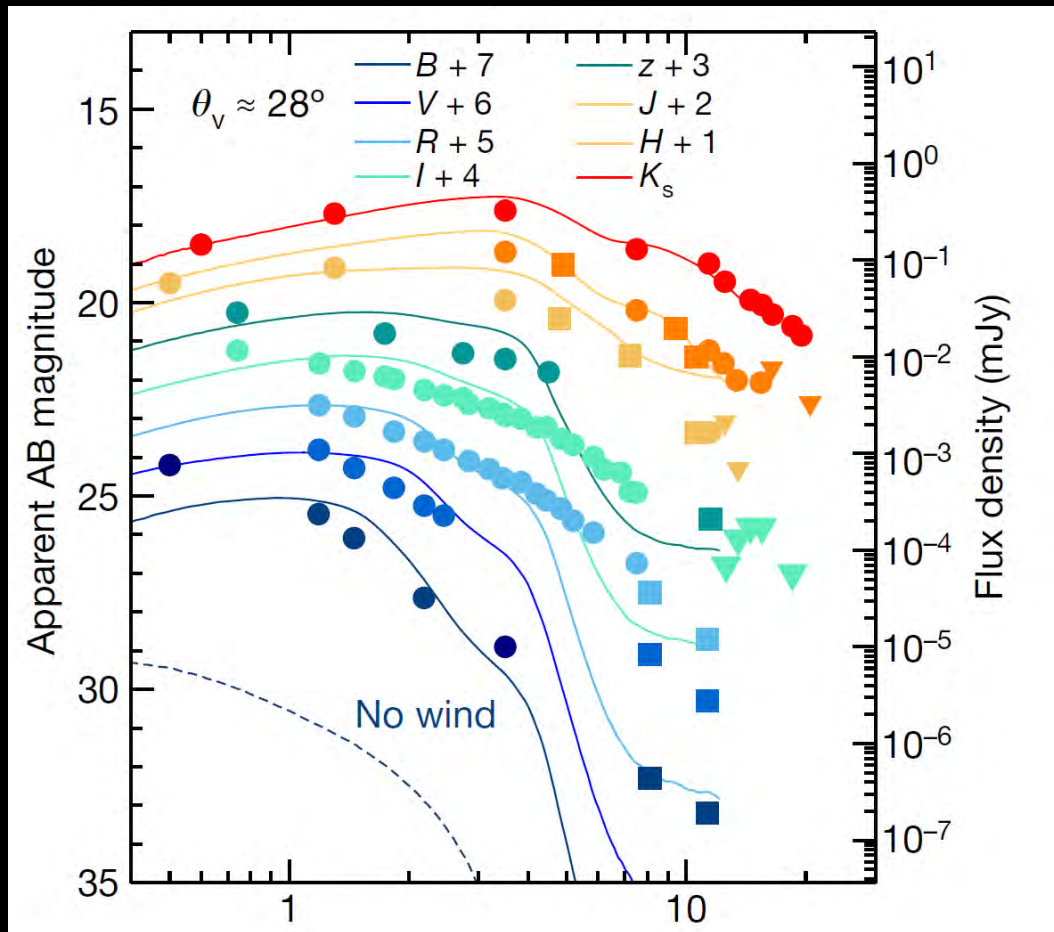
KMTNET IMAGE OF GW170817



- Blue → Red evolution



COMPARISON WITH KILONOVA MODEL



- $M_{ej} \sim 0.01 M_{\odot}$
- Off-axis GRB/Wind model

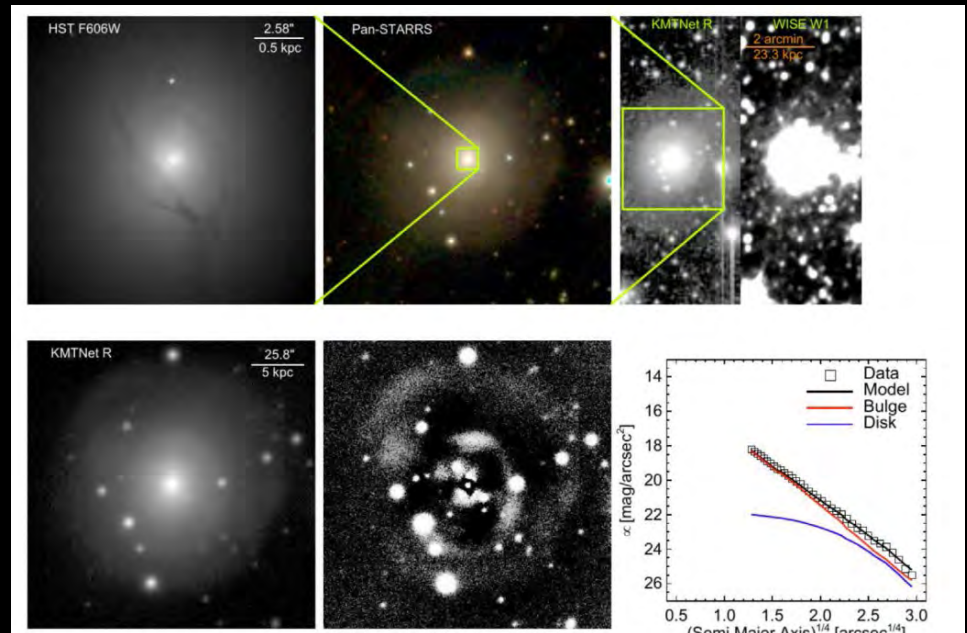
→ Kilonova!

Troja, E. et al. (2017, Nature)



NGC 4993 STUDY

- E with $M^* \sim 10^{10-11} M_{\odot}$
- Old ($t > 3$ Gyr)
- GW event at $\sim R_{\text{eff}}$
- $D_L \sim 40$ Mpc (FP + GC)



Im et al. (2017, ApJL) [Oct. 3, submitted, Oct. 13, accepted]
Lee, Kang, & Im, 2018, ApJL

O3 PREDICTION (2018.11.12, GW CONF@IBS, BY IM)

- BNS range: 120 Mpc (LIGO), 65 Mpc (Virgo)

Burst of GW detections expected

Expected GW events in O3 run

Im's formula

$$\text{Sqrt}(1 \times 50) = 7 \pm 1 \text{ BNS}$$

vs

No, ≤ 5 or ≥ 9
Let's bet



KGW

32 BBH

BH-NS: 1/10 of BNS

**So far, 6 BNS,
BH-NS, Massgap
with >90%**



KOREA MICROLENSING TELESCOPE NETWORK (KMTNET)

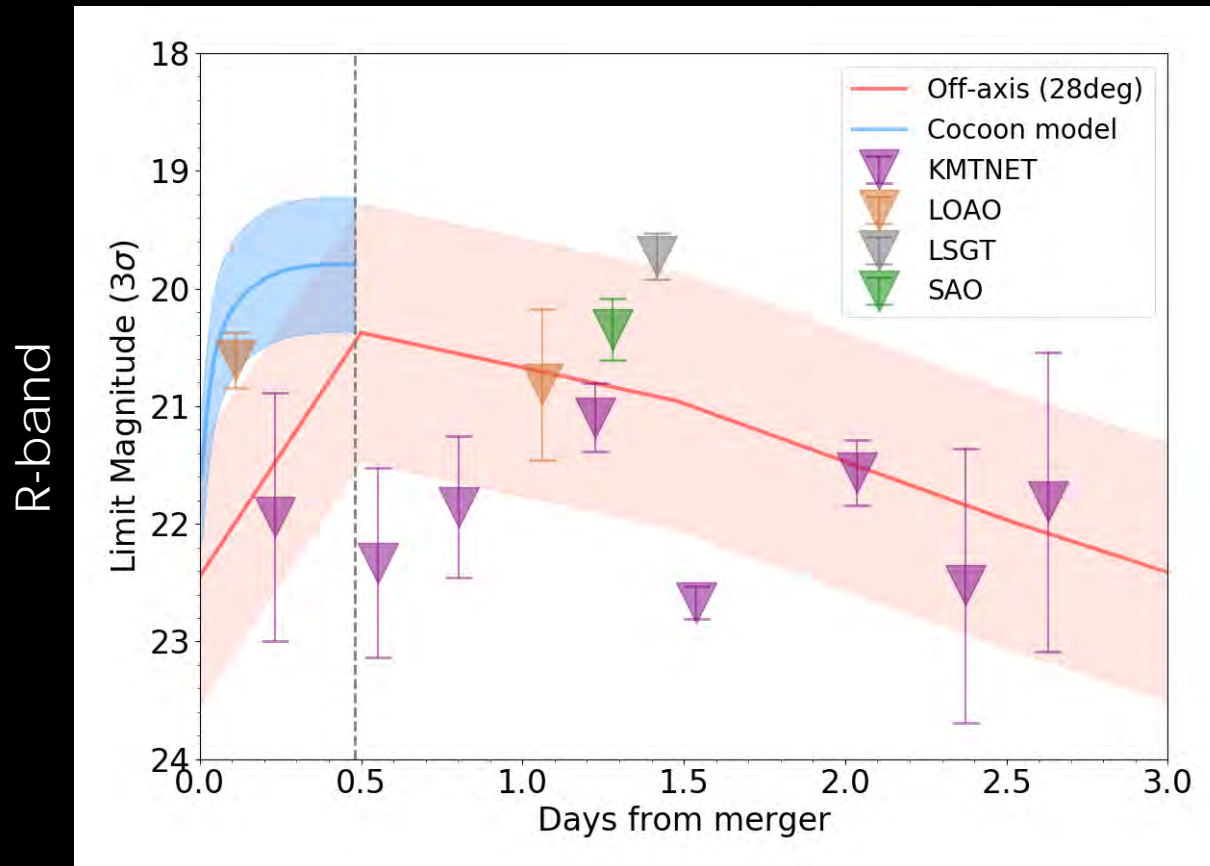
- Three 1.6m telescopes at southern hemisphere
- Limiting mag: 23 AB mag ($5-\sigma$) in 6 min
- FOV: 4 deg²
- 24 hr coverage



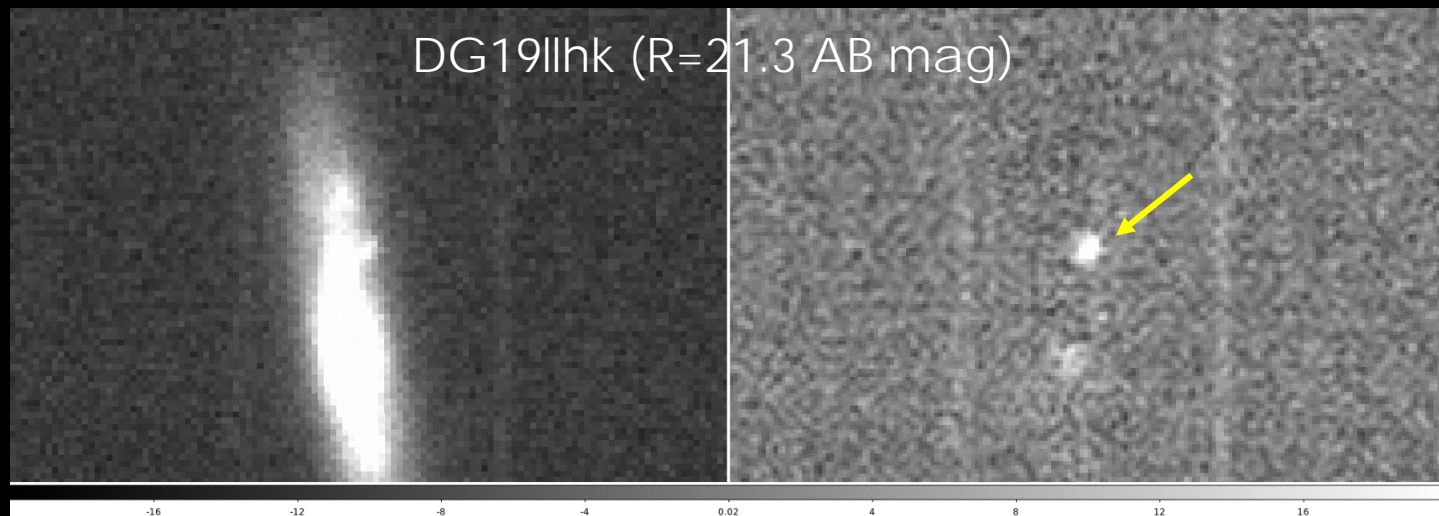
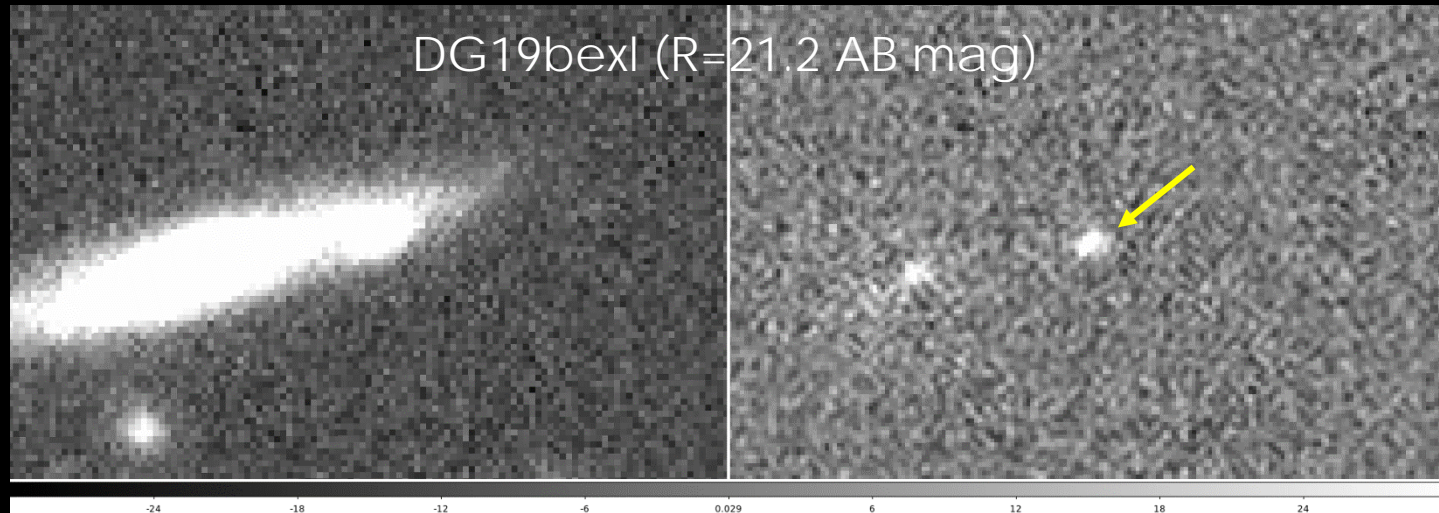


GECKO DEPTHS

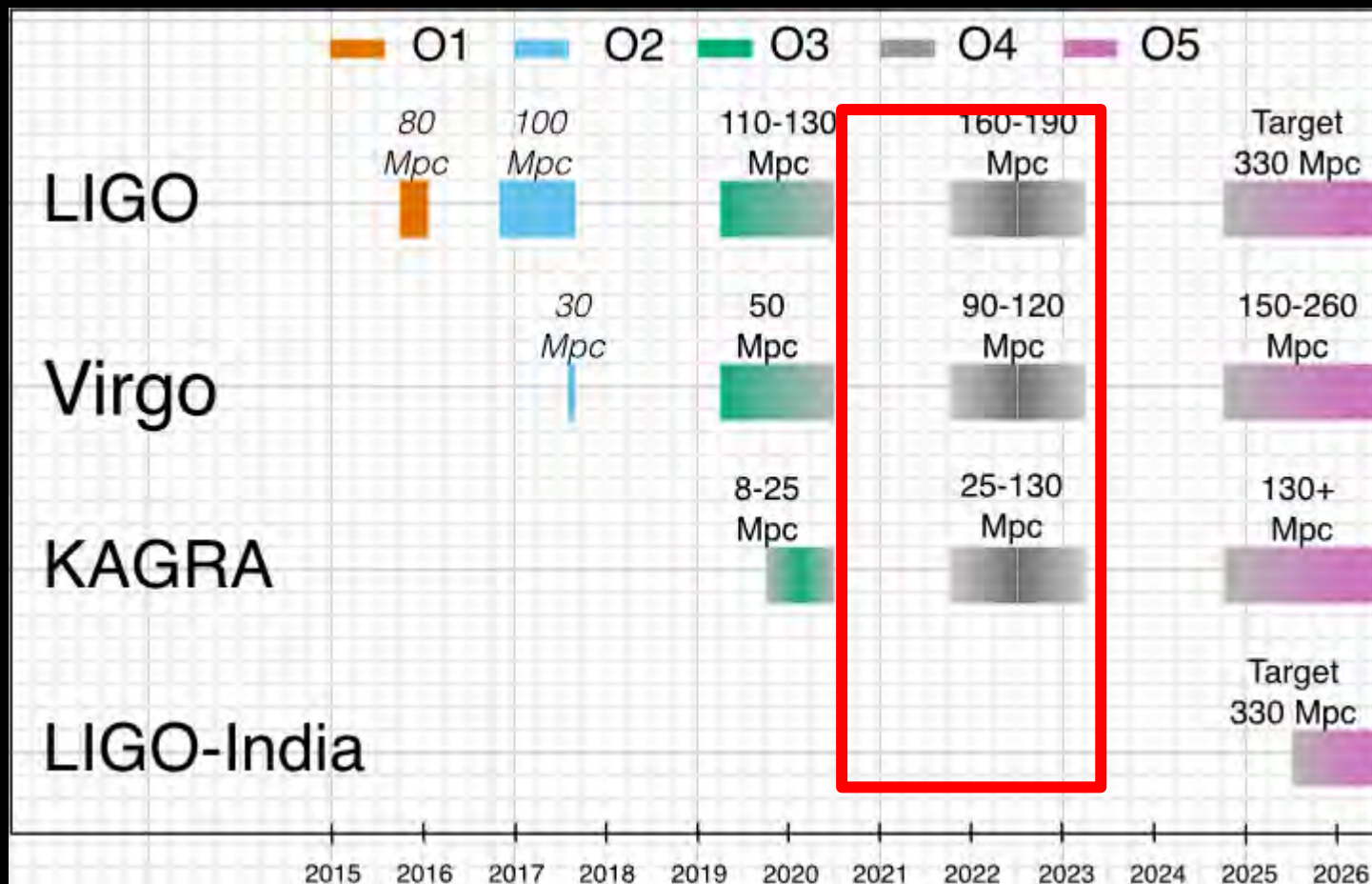
- Sensitive enough for ~150 Mpc events



TRANSIENTS IN S190510G (KMTNET)



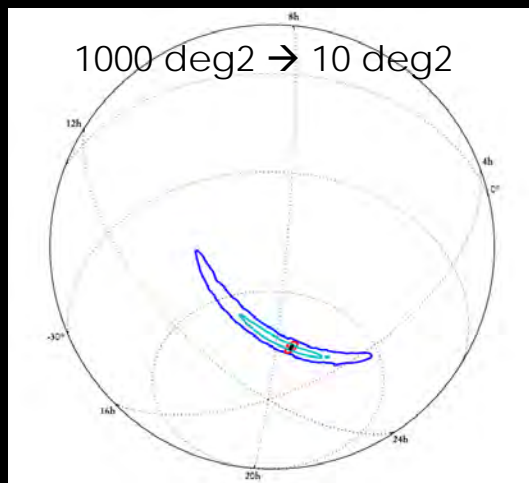
OUTLOOK FOR EVENTS IN 2021~



EXPECTED EVENT RATES & CREDIBLE REGION

- BNS rate – [4-80] to [11-180] ~ 18 – 45 per year
- CR: ~3 with 5 deg², ~15 with < 20 deg²

GW150914



Arxiv1304.0670

Epoch	2015–2016	2016–2017	2018–2019	2020+	2024+
Planned run duration	4 months	9 months	12 months	(per year)	(per year)
Expected burst range/Mpc	LIGO 40–60 Virgo — KAGRA —	60–75 20–40 —	75–90 40–50 —	105 40–70 —	105 80 100
Expected BNS range/Mpc	LIGO 40–80 Virgo — KAGRA —	80–120 20–65 —	120–170 65–85 —	190 65–115 —	190 125 140
Achieved BNS range/Mpc	LIGO 60–80 Virgo — KAGRA —	60–100 25–30 —	— — —	— — —	— — —
Estimated BNS detections	0.05–1	0.2–4.5	1–50	4–80	11–180
Actual BNS detections	0	1	—	—	—
90% CR	% within 5 deg ²	< 1	1–5	1–4	3–7
	20 deg ²	< 1	7–14	12–21	14–22
	median/deg ²	460–530	230–320	120–180	110–180
Searched area	% within 5 deg ²	4–6	15–21	20–26	23–29
	20 deg ²	14–17	33–41	42–50	44–52

O4 Update (2019-10): BNS with CR < 48 deg²: $\sqrt{1 \times 42} = 6.5/\text{yr}$



MMA WITH KMTNET (2020-2023)

- TOO of GW/neutrino sources to identify and characterize their nature
- 168 hrs per site per year (total 504 hrs per year) – 3 year program
- 22 researchers from SNU, KASI, NIMS, Ewha, NYSC, KIAA

KMTNet Proposal (2020-10-01 to 2023-09-30)

Page 1

Title: Multi-Messenger Astronomy with KMTNet

Research Team

P.I. Myungshin Im (Seoul National University)

Co.I. Chung-Uk Lee (KASI), Seung-Lee Kim (KASI), Hyung Mok Lee (KASI), Sung-Chul Yoon (SNU), Joonho Kim (SNU), Gregory S. H. Paek (SNU), Sophia Kim (SNU), Sungyong Hwang (SNU), Gu Lim (SNU), Changsu Choi (SNU), Seong-Kook Lee (SNU), Yongmin Yoon (SNU), Yongjung Kim (SNU), Dohyeong Kim (KIAA), Wonseok Kang (NYSC), Taewoo Kim (NYSC), Hyun-Il Sung (KASI), Z. Lucas Uhm (KASI), Soojong Pak (KHU), Chunglee Kim (Ewha Womans Univ.), Sanghoon Oh (NIMS)



OBSERVATION PLAN

GW type	CR class	Filter set	Time/event (1st epoch)	Time/event (2nd epoch)	Event rate (/year/whole sky)
BNS or NS-BH merger	A	B,V,R, I	~80 min	~20 min	3
	B	B, R	~100 min	~50 min	15
	C	R (bright) or B (dark)	~300 min	~300 min	42
BBH merger	A	R	~20 min	~20 min	15
Unexpected	Any	R	~150 min	~150 min	0.1?

A: $CR < 5 \text{ deg}^2$
B: $5 \text{ deg}^2 < CR < 20 \text{ deg}^2$
C: $CR > 20 \text{ deg}^2$

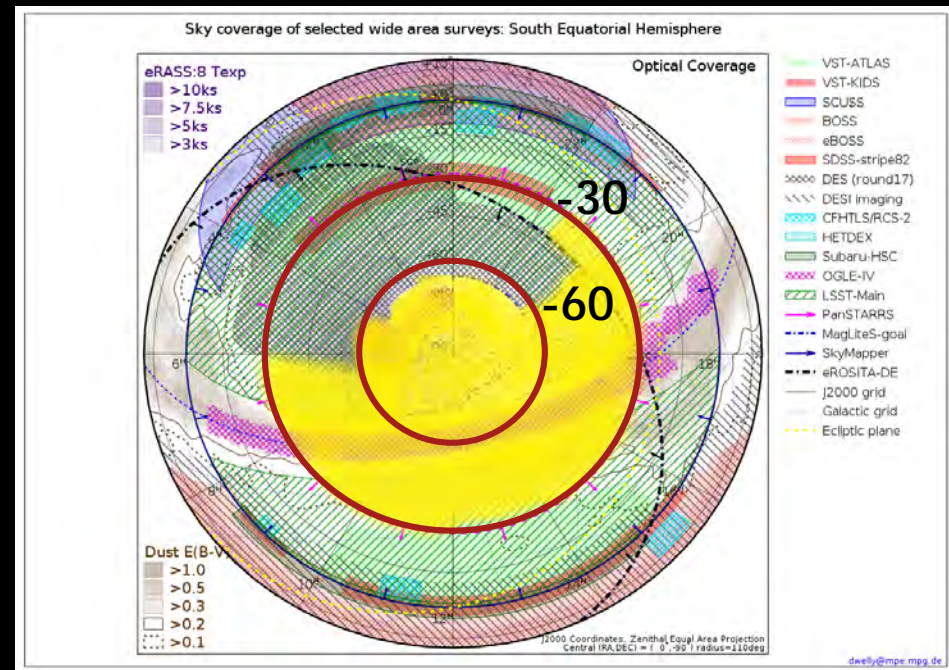
- Rapid follow-up of the entire CR regions
- 4 min per pixel → 22 – 22.5 mag depth (BVRI)
- 1/3 O4 EM counterparts may be uncovered by KMTNet



KMT SYNOPSIS SURVEY OF SOUTHERN SKY (KS4)

- Wide-field imaging survey of Southern Sky ($\sim 7000 \text{ deg}^2$)
- 2020~2023
- 37 Co-Is from Korea, Australia, South Africa

Filter	AB mag ($5-\sigma$)
B	23.5
V	23.2
R	23.2
I	22.5
Z	21.5





SMALL TELESCOPE NETWORK

소형망원경 네트워크(소망넷)

- Network of 0.5 – 1m class telescopes in Korea
- Operation from 2020

Seoul/Metroplitan

SNU
0.6m, 1m
Kyunghee Univ.
0.8m

Jeolla-Namdo

NYSC
1m



Chunchung-Bukdo

CBNU
0.6m, 1m
SOAO
0.6m

Daegu

Daegu Sci Center
1m

Oversea

US
Lemmon 1m
SSO(Australia)
LSGT 0.4m

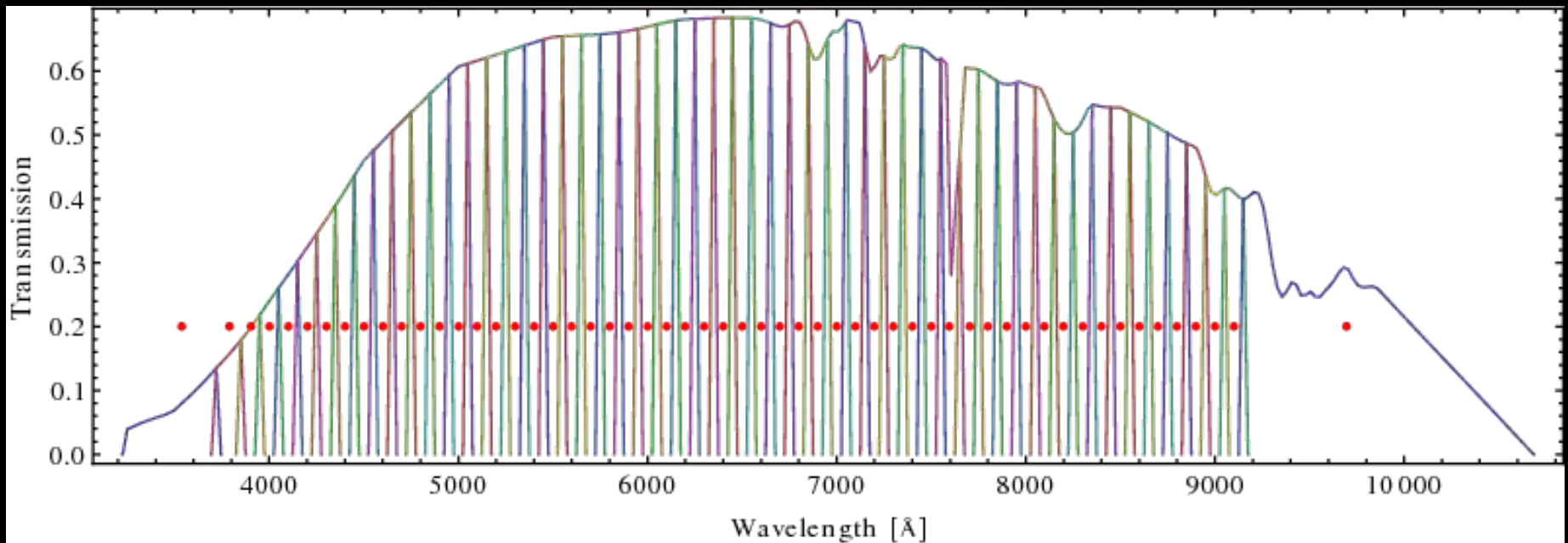
7-DIMENSIONAL TELESCOPE (7DT)

- 40-50 x 0.36m Wide-field telescopes
- Each telescope observes different wavelength



56개의 중대역 필터

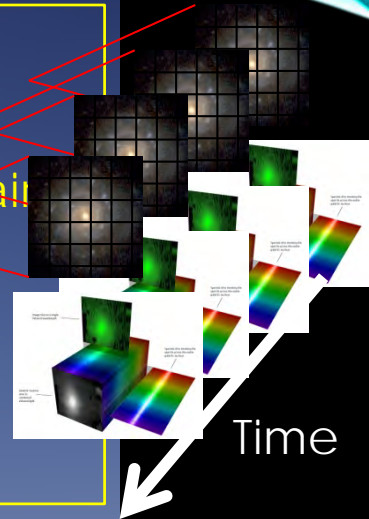
- 파장폭: 20nm
- 파장간격: 10nm
- R ~65의 저분산 스펙트럼 획득
- 필터 휠 부착, 필요시 광대역 및 협대역 필터 사용



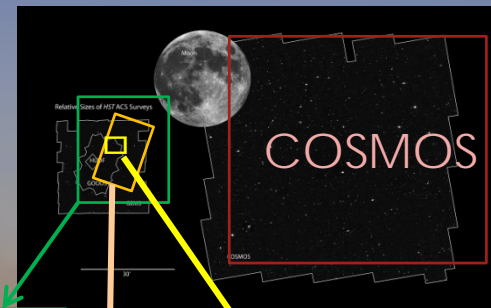
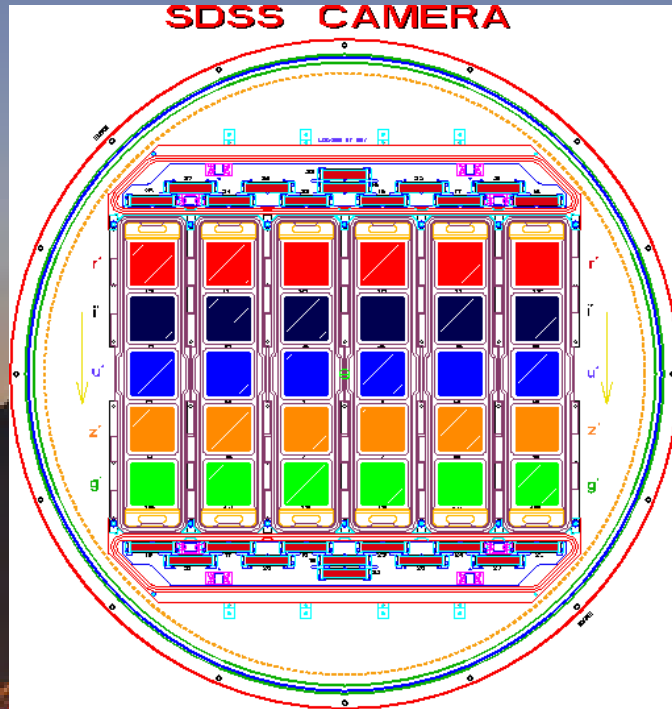
6 deg

2.34 deg

Single FOV of 7DT
Wide + Each pixel contains
spectral information



3.12 deg



GEMS

GOODS

HUDF



GECKO FUTURE

- GW-EM MMA: New frontier of Astronomy
- Be ready, and get lucky

